15.E: Nuclear Chemistry (Exercises)

Exerises (Radioactivity)

1. Define radioactivity.

2. Give an example of a radioactive element. How do you know if it is radioactive?

3. How many protons and neutrons are in each isotope?

   a. $^{11}_{5}\mathrm{B}$
   b. $^{27}_{13}\mathrm{Al}$
   c. $^{56}\mathrm{Fe}$
   d. $^{224}\mathrm{Rn}$

4. How many protons and neutrons are in each isotope?

   a. $^{2}_{1}\mathrm{H}$
   b. $^{112}_{48}\mathrm{Cd}$
   c. $^{252}\mathrm{Es}$
   d. $^{40}\ \mathrm{K}$

5. Describe an alpha particle. What nucleus is it equivalent to?

6. Describe a beta particle. What subatomic particle is it equivalent to?

7. What are gamma rays?

8. Why is it inappropriate to refer to gamma rays as "gamma particles"?

9. Plutonium has an atomic number of 94 . Write the nuclear equation for the alpha particle emission of plutonium-244. What is the daughter isotope?

10. Francium has an atomic number of 87 . Write the nuclear equation for the alpha particle emission of francium-212. What is the daughter isotope?

11. Tin has an atomic number of 50 . Write the nuclear equation for the beta particle emission of tin-121. What is the daughter isotope?

12. Technetium has an atomic number of 43 . Write the nuclear equation for the beta particle emission of technetium-99. What is the daughter isotope?

13. Energies of gamma rays are typically expressed in units of megaelectron volts (MeV), where $1\mathrm{MeV} = 1.602 \times 10^{-13}\ \mathrm{J}$. Using the data provided in the text, calculate the energy in megaelectron volts of the gamma ray emitted when radon-222 decays.

14. The gamma ray emitted when oxygen-19 gives off a beta particle is $0.197\mathrm{MeV}$. What is its energy in joules? (See Exercise 13 for the definition of a megaelectron volt.)

15. Which penetrates matter more deeply-alpha particles or beta particles? Suggest ways to protect yourself against both particles.

16. Which penetrates matter more deeply-alpha particles or gamma rays? Suggest ways to protect yourself against both emissions.

17. Define nuclear fission.

18. What general characteristic is typically necessary for a nucleus to undergo spontaneous fission?

Answers

1. Radioactivity is the spontaneous emission of particles and electromagnetic radiation from nuclei of unstable atoms.

3.

   a. 5 protons; 6 neutrons
   b. 13 protons; 14 neutrons
   c. 26 protons; 30 neutrons
   d. 86 protons; 138 neutrons

5. An alpha particle is a collection of two protons and two neutrons and is equivalent to a helium nucleus.

7. Gamma rays are high-energy electromagnetic radiation given off in radioactive decay.

9. $^{244}_{94}\text{Pu} \rightarrow {}^{240}_{92}\text{U} + {}^{4}_{2}\text{He}$; daughter isotope: ^{240}U

11. $^{121}_{50}\text{Sn} \rightarrow {}^{121}_{51}\text{Sb} + {}^{0}_{-1}\text{e}$; daughter isotope: ^{121}Sb

13. 0.51MeV

15. Beta particles penetrate more. A thick wall of inert matter is sufficient to block both particles.

17. Nuclear fission is the breaking down of large nuclei into smaller nuclei, usually with the release of excess neutrons.

Exercises (Half-Life)

1. Do all isotopes have a half-life? Explain your answer.

2. Which is more radioactive-an isotope with a long half-life or an isotope with a short half-life?

3. How long does it take for 1.00 g of palladium-103 to decay to 0.125 g if its halflife is 17.0 d?

4. How long does it take for 2.00 g of niobium-94 to decay to 0.0625 g if its halflife is $20,000\text{y}$?

5. It took 75y for 10.0 g of a radioactive isotope to decay to 1.25 g. What is the half-life of this isotope?

6. It took 49.2 s for 3.000 g of a radioactive isotope to decay to 0.1875 g. What is the half-life of this isotope?

7. The half-live of americium-241 is 432y. If 0.0002 g of americium-241 is present in a smoke detector at the date of manufacture, what mass of americium-241 is present after 100.0y? After $1,000.0\text{y}$?

8. If the half-life of tritium (hydrogen-3) is 12.3y, how much of a 0.00444 g sample of tritium is present after 5.0y ? After 250.0y ?

9. Explain why the amount left after 1,000.0 y in Exercise 7 is not one-tenth of the amount present after 100.0y, despite the fact that the amount of time elapsed is 10 times as long.

10. Explain why the amount left after 250.0y in Exercise 8 is not one-fiftieth of the amount present after 5.0y, despite the fact that the amount of time elapsed is 50 times as long.

11. An artifact containing carbon-14 contains $8.4 \times 10^{-9}\text{ g}$ of carbon-14 in it. If the age of the artifact is $10,670\text{y}$, how much carbon-14 did it have originally? The half-life of carbon-14 is 5,730 y.

12. Carbon-11 is a radioactive isotope used in positron emission tomography (PET) scans for medical diagnosis. Positron emission is another, though rare, type of radioactivity. The half-life of carbon-11 is 20.3 min. If $4.23 \times 10^{-6}\text{ g}$ of carbon-11 is left in the body after 4.00 h, what mass of carbon-11 was present initially?

Answers

1. Only radioactive isotopes have a half-life.

3. 51.0 d

5. 25y

7. $0.000170\text{ g}; 0.0000402\text{ g}$

9. Radioactive decay is an exponential process, not a linear process.

11. $3.1 \times 10^{-8}\text{ g}$

Exercises (Units of Radioactivity)

1. Define rad.

2. Define rem.

3. How does a becquerel differ from a curie?

4. Define curie.

5. A sample of radon gas has an activity of 140.0mCi If the half-life of radon is $1,500\text{y}$, how long before the activity of the sample is 8.75mCi?

6. A sample of curium has an activity of $1,600\ \text{Bq}$. If the half-life of curium is 24.0 s, how long before its activity is $25.0\ \text{Bq}$?

7. If a radioactive sample has an activity of $65\mu\text{Ci}$, how many disintegrations per second are occurring?

8. If a radioactive sample has an activity of $7.55 \times 10^5\ \text{Bq}$, how many disintegrations per second are occurring?

9. A sample of fluorine-20 has an activity of 2.44mCi If its half-life is 11.0 s, what is its activity after 50.0 s ?

10. Strontium-90 has a half-life of 28.1y. If $66.7\ \text{Bq}$ of pure strontium-90 were allowed to decay for 15.0y, what would the activity of the remaining strontium-90 be?

11. How long does it take $100.0\text{mCi}$of fluorine-20 to decay to 10.0mCiif its halflife is 11.0 s ?

12. Technetium-99 is used in medicine as a source of radiation. A typical dose is 25 mCi. How long does it take for the activity to reduce to 0.100mCi? The half-life of ^{99}Tc is $210,000\text{y}$.

13. Describe how a radiation exposure in rems is determined.

14. Which contributes more to the rems of exposure-alpha or beta particles? Why?

15. Use Table 15.4 "Effects of Short-Term Exposure to Radioactivity and Radiation" to determine which sources of radiation exposure are inescapable and which can be avoided. What percentage of radiation is unavoidable?

16. Name two isotopes that contribute to the radioactivity in our bodies.

17. Explain how a film badge works to detect radiation.

18. Explain how a Geiger counter works to detect radiation.

Answers

1. a unit of radioactive exposure equal to $0.01\ \text{J}$ of energy per gram of tissue

3. A becquerel is 1 decay/s, whereas a curie is 3.7×10^{10} decays/s.

5. $6.0 \times 10^3\text{y}$

7. 2.41×10^6 disintegrations per second

9. 0.104mCi

11. 36.5 s

13. by using a film badge, which is exposed by the radiation, or a Geiger counter

15. Radioactive atoms in the body, most terrestrial sources, cosmic sources, and nuclear energy sources are likely unavoidable, which is about 27% of the total exposure. If exposure to radon gas is added, the total unavoidable exposure increases to 82%.

17. Film is exposed by the radiation. The more radiation film is subjected to, the more exposed it becomes.

Exercises (Uses of Radioactive Isotopes)

1. Define tracer and give an example of how tracers work.

2. Name two isotopes that have been used as tracers.

3. Explain how radioactive dating works.

4. Name two isotopes that have been used in radioactive dating.

5. The current disintegration rate for carbon-14 is $14.0\ \text{Bq}$. A sample of burnt wood discovered in an archeological excavation is found to have a carbon-14 disintegration rate of $3.5\ \text{Bq}$. If the half-life of carbon-14 is $5,730\text{y}$, approximately how old is the wood sample?

6. A small asteroid crashes to Earth. After chemical analysis, it is found to contain 1 g of technetium-99 to every 3 g of ruthenium-99, its daughter isotope. If the half-life of technetium-99 is $210,000\text{y}$, approximately how old is the asteroid?

7. What is a positive aspect of the irradiation of food?

8. What is a negative aspect of the irradiation of food?

9. Describe how iodine-131 is used to both diagnose and treat thyroid problems.

10. List at least five organs that can be imaged using radioactive isotopes.

11. Which radioactive emissions can be used therapeutically?

12. Which isotope is used in therapeutics primarily for its gamma ray emissions?

Answers

1. A tracer is a radioactive isotope that can be detected far from its original source to trace the path of certain chemicals. Hydrogen-3 can be used to trace the path of water underground.

3. If the initial amount of a radioactive isotope is known, then by measuring the amount of the isotope remaining, a person can calculate how old that object is since it took up the isotope.

5. $11,500\text{y}$

7. increased shelf life (answers will vary)

9. The thyroid gland absorbs most of the iodine, allowing it to be imaged for diagnostic purposes or preferentially irradiated for treatment purposes.

11. gamma rays

Exercises (Nuclear Energy)

1. According to Einstein's equation, the conversion of 1.00 g of matter into energy generates how much energy?

2. How much matter needs to be converted to energy to supply 400 kJ of energy, the approximate energy of 1 mol of $\text{C}-\text{H}$ bonds? What conclusion does this suggest about energy changes of chemical reactions?

3. In the spontaneous fission of lead-208, the following reaction occurs: ${}^{208}\text{Pb} \rightarrow {}^{129}\text{I} + {}^{76}\text{Cu} + 3{}^{1}\text{n}$
For every mole of lead-208 that decays, 0.1002 g of mass is lost. How much energy is given off per mole of lead-208 reacted?

4. In the spontaneous fission of radium-226, the following reaction occurs: ${}^{226}\text{Ra} \rightarrow {}^{156}\text{Pm} + {}^{68}\text{Co} + 2{}^{1}\text{n}$
For every mole of radium-226 that decays, 0.1330 g of mass is lost. How much energy is given off per mole of radium-226 reacted?

5. Recalculate the amount of energy from Exercise 3 in terms of the number of grams of lead-208 reacted.

6. Recalculate the amount of energy from Exercise 4 in terms of the number of grams of radium-226 reacted.

7. What is the energy change of this fission reaction? Masses in grams are provided.

$$\underset{241.0569}{\overset{241}{}}\text{Pu} \rightarrow \underset{139.9106}{\overset{140}{}}\text{Ba} + \underset{89.9077}{\overset{90}{}}\text{Sr} + \underset{11\times1.0087}{111}{}^{1}\text{n}$$

8. What is the energy change of this fission reaction? Masses in grams are provided.

9. The two rarer isotopes of hydrogen-deuterium and tritium-can also be fused to make helium by the following reaction:

$${}^{2}\text{H} + {}^{3}\text{H} \rightarrow {}^{4}\text{He} + {}^{1}\text{n}$$

In the course of this reaction, 0.01888 g of mass is lost. How much energy is given off in the reaction of 1 mol of deuterium and tritium?

10. A process called helium burning is thought to occur inside older stars, forming carbon:

$$3{}^{4}\text{He} \rightarrow {}^{12}\text{C}$$

If the reaction proceeds with 0.00781 g of mass lost on a molar basis, how much energy is given off?

11. Briefly describe how a nuclear reactor generates electricity.

12. Briefly describe the difference between how a nuclear reactor works and how a nuclear bomb works.

13. What is a chain reaction?

14. Why must uranium be enriched to supply nuclear energy?

Answers

1. $9.00 \times 10^{13}\ \text{J}$

3. $9.02 \times 10^{12}\ \text{J}$

5. $4.34 \times 10^{10}\ \text{J/g}$

7. $-1.28 \times 10^{13}\ \text{J}$

9. $1.70 \times 10^{12}\ \text{J}$

11. A nuclear reactor controls a nuclear reaction to produce energy in usable amounts. The energy produced generates steam, which is used to turn a turbine that generates electricity for general use.

13. a process that generates more reaction pathways for each previous reaction

Additional Exercises

1. Given that many elements are metals, suggest why it would be unsafe to have radioactive materials in contact with acids.

2. Many alpha-emitting radioactive substances are relatively safe to handle, but inhaling radioactive dust can be very dangerous. Why?

3. Uranium can be separated from its daughter isotope thorium by dissolving a sample in acid and adding sodium iodide, which precipitates thorium(III) iodide:

$$\text{Th}^{3+}(\text{aq}) + 3\text{I}^{-}(\text{aq}) \rightarrow \text{ThI}_3(\text{s})$$

If $0.567\ \text{g}$ of Th^{3+} were dissolved in solution, how many milliliters of $0.500\text{M}\ \text{NaI(aq)}$ would have to be added to precipitate all the thorium?

4. Thorium oxide can be dissolved in acidic solution:

$$\text{ThO}_2(\text{s}) + 4\text{H}^{+} \rightarrow \text{Th}^{4+}(\text{aq}) + 2\text{H}_2\text{O}(\ell)$$

How many milliliters of $1.55\text{M}\ \text{HCl(aq)}$ are needed to dissolve $10.65\ \text{g}$ of ThO_2 ?

5. Radioactive strontium is dangerous because it can chemically replace calcium in the human body. The bones are particularly susceptible to radiation damage. Write the nuclear equation for the beta emission of strontium-90.

6. Write the nuclear equation for the beta emission of iodine-131, the isotope used to diagnose and treat thyroid problems.

7. A common uranium compound is uranyl nitrate hexahydrate $[\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$. What is the formula mass of this compound?

8. Plutonium forms three oxides: PuO, PuO_2, and Pu_2O_3. What are the formula masses of these three compounds?

9. A banana contains 600mg of potassium, 0.0117% of which is radioactive potassium-40. If $1\ \text{g}$ of potassium-40 has an activity of $2.626 \times 10^5\ \text{Bq}$, what is the activity of a banana?

10. Smoke detectors typically contain about 0.25mg of americium-241 as part of the smoke detection mechanism. If the activity of $1\ \text{g}$ of americium-241 is $1.26 \times 10^{11}\ \text{Bq}$, what is the activity of americium-241 in the smoke detector?

11. Uranium hexafluoride (UF_6) reacts with water to make uranyl fluoride $(\text{UO}_2\ \text{F}_2)$ and HF. Balance the following reaction:

$$\text{UF}_6 + \text{H}_2\text{O} \rightarrow \text{UO}_2\ \text{F}_2 + \text{HF}$$

12. The cyclopentadienyl anion $(\text{C}_5\text{H}_5{}^{-})$is an organic ion that can make ionic compounds with positive ions of radioactive elements, such as Np^{3+}. Balance the following reaction:

$$\text{NpCl}_3 + \text{Be}(\text{C}_5\text{H}_5)_2 \rightarrow \text{Np}(\text{C}_5\text{H}_5)_3 + \text{BeCl}_2$$

13. If the half-life of hydrogen-3 is 12.3y, how much time does it take for 99.0% of a sample of hydrogen-3 to decay?

14. If the half-life of carbon-14 is $5,730\text{y}$, how long does it take for 10.0% of a sample of carbon-14 to decay?

15. Although bismuth is generally considered stable, its only natural isotope, bismuth-209, is estimated to have a half-life of $1.9 \times 10^{19}\text{y}$. If the universe is estimated to have a lifetime of $1.38 \times 10^{10}\text{y}$, what percentage of bismuth-209 has decayed over the lifetime of the universe? (Hint: Be prepared to use a lot of decimal places.)

16. The most common isotope of uranium (uranium-238) has a half-life of $4.5 \times 10^9\ \text{y}$. If the universe is estimated to have a lifetime of $1.38 \times 10^{10}\text{y}$, what percentage of uranium-238 has decayed over the lifetime of the universe?

17. Refer to Table 15.3 "Average Annual Radiation Exposure (Approximate)" and separate the sources of radioactive exposure into voluntary and involuntary sources. What percentage of radioactive exposure is involuntary?

18. With reference to Table 15.3 "Average Annual Radiation Exposure (Approximate)" and Exercise 17, suggest ways that a practical person can minimize exposure to radioactivity.

Answers

1. Acids can dissolve many metals; a spilled acid can lead to contamination.

3. $14.7\ \text{mL}$

5. $^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\text{e}$

7. $502.15\ \text{g/mol}$

9. about $18\ \text{Bq}$

11. $\text{UF}_6 + 2\text{H}_2\text{O} \rightarrow \text{UO}_2\ \text{F}_2 + 4\text{HF}$

13. 81.7y

15. about 0.000000005%

17. Radioactive atoms in the body, terrestrial sources, and cosmic sources are truly involuntary, which is about 27% of the total. Radon exposure, medical sources, consumer products, and even nuclear energy sources can be avoided.
